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Basic Limnology of Two Crater Lakes in Western Victoria

By B. V. Timms*

Abstract: Lake Mumblin, near Terang, and Lake Surprise, near Macarthur are the only true crater lakes *sensu stricto* in Victoria. Each is small, near 12 m deep and enclosed by steep crater walls.

Both lakes stratify in summer. Extreme wind protection and opaque water result in sharp thermoclines and lower heat budgets than expected for southern Victoria. The lake waters are slightly alkaline, hard and dominated by Na^+ and Cl^- ions.

Of the three communities investigated, zooplankton, littoral weedbed invertebrates and benthos, not one, except zooplankton in Surprise, is as diverse as that in freshwater lakes elsewhere in Victoria.

Mumblin appears to be relatively more productive than Surprise.

INTRODUCTION

Of the many lakes resulting from past volcanic activity in the Western District of Victoria, only two are true crater lakes (*sensu* Hutchinson 1957): Lake Mumblin (38°20′S, 142°56′E), 9 km south of Terang, in a basalt-rimmed crater of a complex volcano known as Staughtons Hill, and Lake Surprise (38°04′S, 141°55′E), an elongated lake in the craters of Mt. Eccles, 9 km southwest of Macarthur (Ollier & Joyce 1964). Both originated in late Pleistocene or Recent times, Mt. Eccles being the most youthful (ca. 5000 years B.P.) eruption point in Victoria (Ollier & Joyce op. cit.).

Although the basic features of salt lakes in the Western District have been surveyed (Bayly & Williams 1966) little is known on the freshwater lakes of the region. Hussainy (1969) has provided some data on Lakes Purrumbete and Elingamite, the author (Timms 1973) has worked intensively on Purrumbete, while Yezdani (1970) reported on macrophytes and phytoplankton of a few lakes, including Mumblin. The present work provides limnological data on the remaining two deep freshwater lakes of the volcanic plains.

MORPHOLOGY

(a) Methods: Each lake was sounded with a 'Koden' SR385 echo sounder. This was mounted on a boat which was moved at near constant speed along a number of transects (4 in Mumblin and 12 in Surprise). The sounder was calibrated by direct soundings with a weighted line. The positions of the transects were determined on an enlarged aerial photograph which also provided an outline of the lake shore. The approximate altitude of each lake was established by the careful use of an aneroid barometer.

The data so obtained were used to construct morphometric maps (Figs. 1 and 2) and to calculate a number of parameters (Table 1).

(b) Results and Discussion: Mumblin (Fig. 1) is round with uniform underwater slopes and a flat bottom. In contrast, Surprise (Fig. 2) is elongated with complex shoreline configuration and variable underwater slopes. Both lakes are of comparable depth and volume (Table 1) but the larger surface area in Surprise results in a smaller mean depth than in Mumblin. There has been considerable sedimentation in both so that sediments are greater than 1 m thick (> 1·5 m in Mumblin, Yezdani 1970), and in addition there is extensive littoral infilling by peat formation in Mumblin. The crater walls around Surprise are steep and high giving considerable protection from wind; Mumblin is less well protected.

The outstanding morphometric parameter is the low shoreline development (1·004) in Mumblin. Crater and maar lakes are usually near-circular (Hutchinson 1957, p. 171) but rarely as per-

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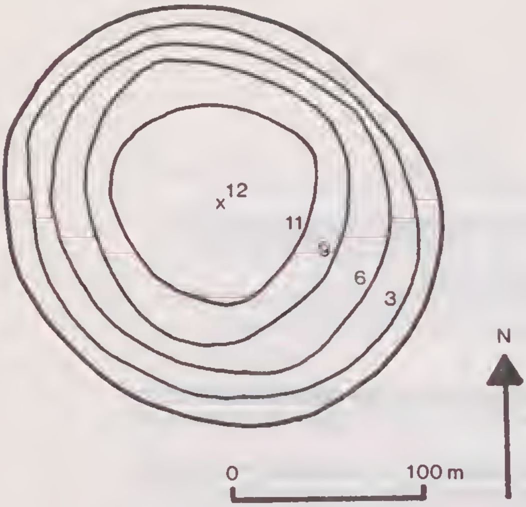

FIG. 1—Morphometric map of Lake Mumblin. Depth in metres.

FIG. 2—Morphometric map of Lake Surprise. Depth in metres.

fectly circular as Mumblin. Although a crater lake, Surprise is irregular in shape, due to the complex physiography of the Mt. Eccles eruption area (Boutakoff 1963). The lake occupies one large crater and two smaller ones which are contiguous.

PHYSICO-CHEMICAL FEATURES

(a) METHODS: Both lakes were visited in July and November 1971 and in February 1972, and there were extra trips to Mumblin in January, April and May 1972.

Temperatures were measured with a resistance thermometer (accurate to ± 0·1°C), dissolved oxygen with the azide modification of the Winkler technique (A.P.H.A. 1971), pH with a Metrohm portable pH meter, and Total Dissolved Solids (hereafter TDS) by evaporation at 105°C. A Secchi disc was used to measure light penetration and water colour was measured against methyl orange standards and expressed in Pt units on the basis of 0·01 mg/l of methyl orange being equivalent to 2·8 Pt units (Hutchinson 1957, p. 413).

Mud particle size was determined by using nested graded sieves, organic matter by per cent loss on ignition at 550° C for 45 minutes, nitrogen by the Kjeldahl method and redox potential using a modification (Timms 1973) of Beadle's method (Beadle 1966).

(b) RESULTS AND DISCUSSION: Mumblin water is light peaty brown in colour (42 Pt units) and light penetration is low (mean Secchi disc transparency, 167 cms) while Surprise water is clear (10 Pt units) and transparency is potentially high (> 8 m) but is considerably reduced in summer by phytoplankton blooms (Table 2).

Annual surface temperatures ranged 9·8°C in Mumblin and 11·8°C in Surprise, with maxima near 20°C—values typical for deep lakes in the Western District (Timms 1973). Both lakes stratify strongly during summer (from November or earlier to April in Mumblin) and circulate in winter (Fig. 3) and hence are of the cheimomictic type (Bayly & Williams 1973). In both the thermocline is sharp and gradients of 2°C/m are not uncommon. Despite limited depth there is in each case a well defined hypolimnion of 2-5 m in thickness. These features must be associated with extreme wind protection and small size and also by low transparency water in Mumblin since in the larger, slightly deeper and more exposed Lake Gnotuk, stratification is shorter in duration, the thermocline less steep and the hypolimnion of lesser thickness (Timms 1973).

The annual heat budget is small in each instance—6370 g cal/cm^2 in Mumblin and 5300 g cal/cm^2 in Surprise. Both of these values are lower than predicted by the relationship between mean depth and heat budget in other Western District lakes during 1969-72 [$(H)_{ba} = 15 \cdot 23 \log_{10} \bar{z} - 5 \cdot 16$] (Timms 1973). At least two factors contribute to this: (a) lower temperatures than normal during the 1971-72 summer and (b) deep mixing in each is hindered by the protected position and/or low transparency water.

Epilimnetic waters generally were close to being saturated with oxygen in Surprise, but not in Mumblin, where saturation values ranged from 60-93%. During stratification hypolimnetic waters

TABLE 1
MORPHOMETRIC PARAMETERS FOR LAKES MUMBLIN AND SURPRISE

Parameter	Mumblin	Surprise
Surface area (ha)	3.8	6.3
Volume ($m^3 \times 10^6$)	0.28	0.34
Max. length (m)	230	675
Max. width (m)		190
Max. depth (m)	12	13
Mean depth (m)	7.3	5.4
Mean depth : Max. depth	0.613	0.415
Length of shoreline (m)	695	1550
Shoreline development	1.004	1.73
Volume development	1.84	1.24
Direction of major axis	(round)	NW↔SE
Altitude a.s.l. (m)	156	88
Mean height of crater walls (m)	27	49

TABLE 2
SECCHI DISC TRANSPARENCY, pH AND TDS IN LAKES MUMBLIN AND SURPRISE

Month	Mumblin			Surprise		
	S.d.(cm)	pH	TDS(ppm)	S.d.(cm)	pH	TDS(ppm)
July	100	7.7	444	404	7.7	380
November	150	7.8	442	820	7.8	371
February	203	7.6	471	150	8.5	394
April	180	8.2	484			
May	204	7.1	469			
Mean values	167	7.7	462	458	8.0	381

quickly deoxygenate and a sharp boundary forms between the deoxygenated hypolimnion and oxygenated epilimnion (Fig. 3). As the epilimnion deepens during autumn this boundary is sharpened and pushed deeper. Deoxygenation is a little more severe in Mumblin than in Surprise. This is evident, not only from the form of the oxygen depth profiles (Fig. 3) but also from the strong odour of hydrogen sulphide in hypolimnetic water from Mumblin.

The water of each lake is slightly alkaline and hard (Table 2). The ionic dominances of Na > Mg > Ca > K and Cl > HCO_3 > SO_4 (Table 3) are typical of freshwater lakes in the Western District (Maddocks 1967).

The sediments in each lake are somewhat different. In Mumblin at 12, 8, and 4 the sediment is a brown-black mud with much visible organic detritus, while in Surprise at 13, 8, 4, and 2 m it is a grey mud containing some mollusc shells. Percent organic matter is greatest in Mumblin and since the nitrogen content in each lake is similar, Mumblin has a higher C/N ratio (Table 4). Based on this ratio, Mumblin's profundal sediment is classified as a dy and that of Surprise as gyttja (Hansen 1959), but there is some doubt on the applicability of this scheme to Western District lakes (Timms 1973). The redox potential of the profundal sediments is lowest in Mumblin (Table 4), but both values are surprisingly high

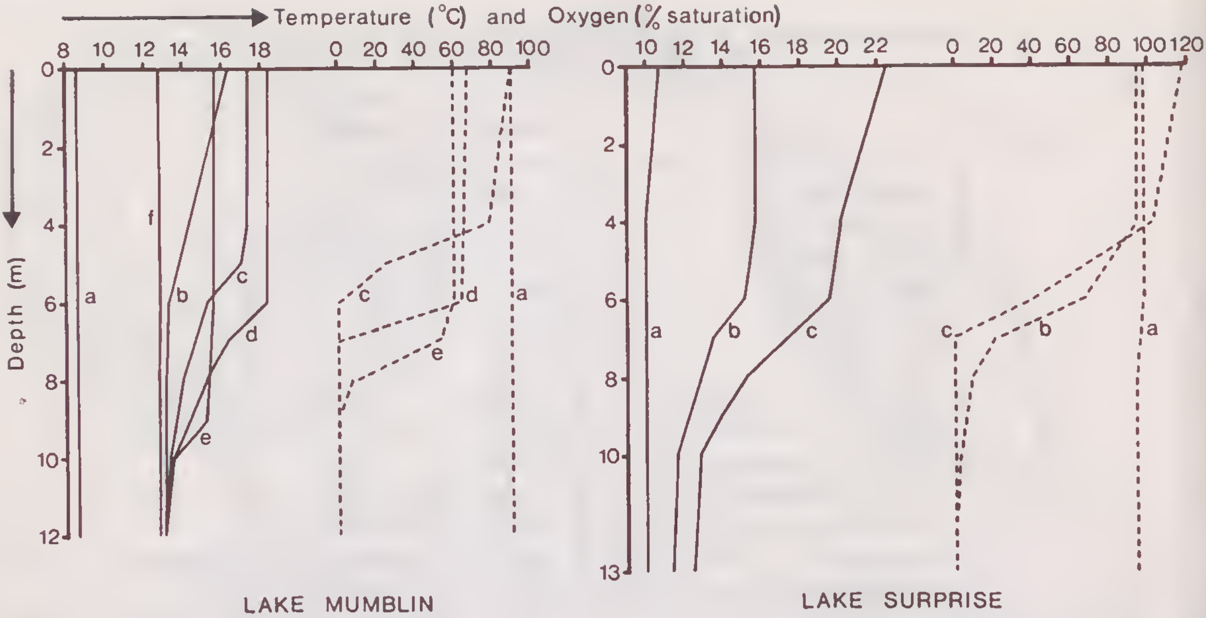

FIG. 3—Depth profiles of temperature (———) and oxygen (— — —) in Lake Mumblin on (a) 1st July, 1971, (b) 14th November, 1972, (c) 5th January, 1972, (d) 22nd February, 1972, (e) 17th April, 1972, and (f) 16th May, 1972 and in Lake Surprise on (a) 5th July, 1971, (b) 23rd November, 1971, and (c) 28th February, 1972.

TABLE 3

CONCENTRATIONS OF MAJOR IONS (meq/l) IN LAKES MUMBLIN AND SURPRISE

Lake	Na^+	K^+	Ca^{++}	Mg^{++}	Sum of Cations	Sum of Anions	Cl^-	HCO_3^-	SO_4^-
Mumblin	4.83	0.17	0.41	1.33	6.74	6.64	5.07	1.15	0.42
Surprise	3.52	0.20	0.77	1.36	5.85	5.78	2.93	2.64	0.21

TABLE 4

SOME FEATURES OF THE SEDIMENTS OF LAKES MUMBLIN AND SURPRISE

Lake and Depth	% by weight of particles < 0.0625 mm	% Organic Matter	% C*	% N	C/N	Eh_7 in mV
Mumblin 12m	97.6	67.5	27.0	2.28	11.8	+328
Surprise 13m	98.8	44.2	17.7	2.23	7.9	+413

* Calculated as 40% organic matter

considering the seasonal deoxygenation of the hypolimnion.

BIOLOGICAL FEATURES

(a) Methods: On each visit, limnetic zooplankton was collected by a vertical haul from the deepest part of the lake with a conical net (33 cm aperture, and mesh size 159μ). Microinvertebrates of littoral weedbeds were caught with a Birge cone net (mouth diameter 18 cm, net mesh size 159μ, and brass cone mesh size 2·5 mm). Larger invertebrates were collected with a coarse pond net (mesh size 0·8 mm). A Birge-Ekman grab of 200 cm^2 gape was used to sample benthos. Triplicate samples from representative depths were collected and sieved through a sieve of mesh size 0·4 mm and the organisms retained were sorted alive in the field. Benthic animals were preserved in 70% alcohol and the remainder in 5% formalin.

(b) Results and Discussion: Zooplankton is abundant and diverse in Surprise (Table 5) and the assemblage of species is typical of that in freshwater lakes in the Western District (Hussainy 1969). In Mumblin there is little zooplankton and few species are present (Table 5). The reason for this is not obvious. Brand (1967) has shown that humic, acid water tends to exclude *Boeckella symmetrica* and *Ceriodaphnia* sp., two common zooplankters in the Western District, but Mumblin, although humified, is alkaline.

In Mumblin, the extensive littoral weedbeds of *Eleocharis sphacelata* R. Br. and *Triglochin procera* R.Br. (Yezdani 1970) harbor at least 34 species of invertebrates while 26 species are recorded from Surprise where weedbeds of *Carex appressa* R.Br. and *Triglochin procera* are localized and sparse. The list in Table 6 is no doubt incomplete. There are inadequate comparative data to comment on species composition, but taken as a whole, diversity is much lower than in Lake Purrumbete where 67 species have been recorded (Timms 1973). Purrumbete has, however, been studied intensively and there are a number of weedbed types.

The benthic faunas are depauperate with only nine species in Mumblin and five in Surprise (Table 7). *Antipodrilus davidis* and *Chaoborus* sp. are dominant in each, while *Chironomus* spp. are seasonally numerous in Mumblin. The data

Table 5

LIMNETIC ZOOPLANKTON OF LAKES MUMBLIN AND SURPRISE

Species	Mumblin			Surprise		
	1/7/71	14/11/71	23/2/72	5/7/71	23/11/71	28/2/72
Boeckella symmetrica Sars				+++	++++	++
Eucylops serrulatus (Fischer)	++	++	++		+	+
Daphnia carinata King				++	+	+++
D. lumholtzi Sars					+	
Ceriodaphnia quadrangula (Muller)				++		
Brachionus sp.	+			+		
Filinia sp.	+	+		+		
Keratella sp.	+					
Unidentified water mite				+	+	+

Code to relative abundance
+ uncommon
++ present
+++ common
++++ very common

TABLE 6
LITTORAL WEEDBED INVERTEBRATES IN LAKES MUMBLIN AND SURPRISE

Species	Mumblin	Surprise
CNIDARIA		
Hydra sp.	+	+
ASCHELMINTHES		
Unidentified nematode	+	
ANNEDIDA : OLIGOCHAETA		
Unidentified naid worm	+	+
ARTHROPODA : CRUSTACEA : OSTRACODA		
Candonocypris assimilis Sars		+
Gomphocythere sp.		+
Newnhamia fenestrata King	+	+
ARTHROPODA : CRUSTACEA : CLADOCERA		
Simocephalus australiensis (Dana)	+	+
Chydorus sphaericus (Muller)		+
Pseudochydorus globosus (Baird)		+
Alona costata Sars	+	
Pleuroxus aduncus (Jurine)		+
ARTHROPODA : CRUSTACEA : COPEPODA		
Eucyclops euacanthus (Sars)	+	
E. serrulatus (Fischer)	+	+
Macrocyclops albidus (Jurine)	+	+
Mesocyclops leuckarti (Claus)	+	
ARTHROPODA : CRUSTACEA : MALACOSTRACA		
Heterias pulsella (Sayce)	+	
Austrochiltonia subtenuis (Sayce)	+	
Paratya australiensis Kemp		+
Cherax destructor Clark	+	
ARTHROPODA : INSECTA		
Atalophlebia sp (australis) group	+	
Aeshna brevistyla Ramb.	+	
Austroagrion cyane Selys	+	
Sigara sp.	+	+
Enithares woodwardi Lansbury	+	+
Naucoris congrex Stal.	+	+
Sphaerodema eques Dufour		+
Atriplectides sp		+
Antiporus interrogationis Clark	+	
A. blokei (?) Clark		+
Enochrus maculiceps Macl.		+
Helochares australis Blkl.		+
Hydrobia australasiae Clark	+	
Limnoxenus zelandicus Brown	+	
Macroporus hamatus Clark	+	+
Necterosoma penicillotum Clark	+	
Rhantus pulverosus Steph.	+	+
Sternopriscus hausordi(?)(Clark)	+	
Ablabesmyia sp		+
Corynoneura sp	+	+
orthoclad sp A	+	
orthoclad sp B	+	
orthoclad sp C		+
Cryptochironomus (Parachironomus group)	+	
Polypedilum sp	+	
Paratanytarsus furvus Glover	+	
Unidentified pyralid larva	+	
MOLLUSCA : GASTROPODA		
Isodorella newcombi (Adams and Angus)	+	+
Total	34	26

(Appendix 1) are sufficient to indicate that there are seasonal fluctuations in numbers of individuals and in their depth distribution, but are inadequate to elucidate these changes. Most obvious, however, is the lack of animals in the hypolimnion of Mumblin in summer, due probably to severe anoxic conditions there (see earlier).

Mean weighted biomass, determined by multiplying the weight of benthos at each depth by the bottom area of the lake represented by that depth and dividing by the area of the lake, is $6 \cdot 8$ g/m^2 in Mumblin and $2 \cdot 6$ g/m^2 in Surprise. In the first lake chaoborids and oligochaetes make equal contributions (42% and 39% respectively) but in Surprise oligochaetes contribute 93% and chaoborids only 5% to the total biomass.

Based on appraisal of a number of criteria (including summer oxygen profiles and benthic biomass) Mumblin can be considered a productive lake, i.e. eutrophic, and Surprise somewhat less productive.

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TABLE 7

RELATIVE ABUNDANCE OF BENTHIC INVERTEBRATES IN LAKES MUMBLIN AND SURPRISE

Species	Mumblin	Surprise
Antipodrilus davidis (Benham)	+++	+++
Procladius villosimanus Kieffer	+	+
Kiefferulus intertinctus Skuse		+
Cryptochironomus curtivalva Kieffer	+	
Chironomus duplex Walker	++	
Chironomus oppositus Walker	+	
Polypedilum nubifer (Skuse)	+	
Chaoborus sp.	+++	++
Economus sp.	+	
Unidentified water mite	+	+

Code for relative abundance as in Table 5

Werribee, Victoria (Ostracoda); Professor Kiefer, Max-Auerback-Institut, Western Germany (Cyclopoida); Dr. Martin, Melbourne University (Chironomidae); Mrs. Morrisey, Perth (Parastacidae); Mr. Nebois, National Museum, Victoria (Hemiptera, Coleoptera); Professor O'Farrell, University of New England (Odonata); Dr. Riek, CSIRO, Canberra (Trichoptera); Dr. Smirnov, USSR Academy of Sciences, Moscow (Chydoridae); and Dr. Smith, National Museum, Victoria (Gastropoda).

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Appendix 1

NUMBER OF BENTHIC ANIMALS PER m^2 AT VARIOUS DEPTHS IN LAKES MUMBLIN AND SURPRISE

Species		Mumblin				Surprise					
		4m	6m	9m	12m	2m	4m	6m	8m	10m	13m
<u>Antipodrilus davidis</u>	A	203		951	110	93	1303		72		-
	B	346		1595	17	17	456		72		1611
	C	-	203	127	-	38	275	1523	550	3960	1743
<u>Procladius villosimanus</u>	A	17		17	-	-	93		-		-
	B	-		72	-	55	-		-		-
	C	17	-	-	-	-	55	-	-	-	-
<u>Kiefferulus intertinctus</u>	A					-	38		-		-
	B					17	-		-		-
	C					-	17		17	-	-
<u>Cryptochironomus curtivalva</u>	A	93		-	-						
	B	17		38	-						
	C	-	-	-	-						
<u>Chironomus duplex</u>)	A	17		38	55						
<u>Chironomus oppositus</u>)	B	165		1798	-						
	C	-	-	-	-						
<u>Polypedilum nubifer</u>	A	17		17	-						
	B	17		165	-						
	C	-	-	-	-						
<u>Chaoborus</u> sp	A	182		2953	3850	-	17		72		182
	B	401		621	72	-	17		38		495
	C	-	55	715	-	-	55	165	55	-	148
<u>Ecnomus</u> sp	A	17		-	-						
	B	-		17	-						
	C	-	-	-	-						
Unidentified water mite	A	-		-	-	-	17		-		-
	B	-		-	-	-	-		-		-
	C	17	-	-	-	-	-	-	-	-	-
TOTALS	A	546		3976	4015	93	1468		144		182
	B	946		4306	89	89	473		110		2106
	C	34	258	842	-	38	402	1688	622	3960	1891

Code:- A - July, 1971
B - November, 1971
C - February. 1972